Net gain of ATP in glycolysis — 8 ATP
Krebs cycle — 24 ATP

RESPIRATION IN PLANTS

1) All breathe ⟶ live

Glucose - favoured substrate for respiration

2) All organisms need energy — for carrying by → Daily life activities → absorption, transport, movement, reproduction, breathing

* Process of breathing very much connected to Process of release of energy from food.

* Energy for "life processes" is obtained by ⟶ Oxidation of some macromolecule (food)

* Only → Cyanobacteria, Green plants — can prepare ⟶ own food (by photosynthesis)

→ trap light energy & convert it into chemical energy

◉ In green plants too

↓

Not all cells, tissues, organs photosynthesise.

↓

Only cells having chloroplast located in SUPERFICIAL LAYERS ⟶ carry out photosynthesis.

Bonds of carbohydrates ← stored in like → Glucose, Sucrose, Starch

Hence even in Green plants, all other organs, tissues, cells that are non green, need food for oxidation

Hence ← Food has to be translocated to all non-green parts

* Animals are ⟶ HETEROTROPHS — obtain ⟶ food from plants → directly (HERBIVORE), → indirectly (CARNIVORE)

* Saprophytes ⟶ Fungi — dependent on ⟶ dead & decaying matter.

* All food that is required for life comes from photosynthesis.

* CELLULAR RESPIRATION → mechanism of breakdown of food material within the cell to release energy, & trapping of this energy for synthesis of ATP.

* Photosynthesis — in ⟶ chloroplast (in eukaryotes), Respiration — in ⟶ cytoplasm/Mitochondria (in eukaryotes)

RESPIRATION — Breaking of C-C bonds of complex comp. through oxidation within cells, leading to release of considerable amt. of energy.

* Compounds that are oxidized → Respiratory Substrate

* During OXIDATION within a cell, all energy contain in a resp substrate

↓

not released in a single step / or free into cell → Its released in a series of SLOW step-wise reactions → controlled by → enzymes

ATP ← in form of ← chemical energy ← trapped as

* Hence, energy released by oxidation in respiration → is not used directly → but used to synthesise ATP → which ① whenever ② wherever can be broken down

Energy trapped in ATP ← energy currency of the cell. ← ATP ← hence

Energy used in various processes.

& → Carbon skeleton produced during respiration → is used as → precursors for biosynthesis of other molecules in cell

Usually, ① carbohydrates, ② proteins, ③ fats, even organic acids can be used as resp. substrate in

- some plants
- under certain conditions

DO PLANTS BREATHE?

plants have a system that ensure availability of O_2.

Plants → no specialised organ for Gaseous exchange but have
- stomata
- Lenticels

for this purpose.

allow gas exchange by diffusion

Several reasons why plants can get along without Respiratory organs

- Each plant part takes care of its own needs (gas exchange needs)
- Very little transport of gases from one plant part to another.
- Plants do not present great demands for gas exchange.
- Roots, stems, Leaves → respire at rates far lower than animals do.
- Distance that gases must diffuse is not great (even in great, bulky plants)

* Each living cell, in a plant is located quite close to surface (THIS IS TRUE FOR LEAVES)

* In stems, living cells are arranged in thin layers inside & hence to the bark.
  - also have openings → LENTICELS
  - Cells in interior → Dead. Mechanical support.

* Thus, most cells of a plant have at least a part of their surface in contact with air

- During photosynthesis only, large volumes of gases exchanged & each leaf is well adapted to take care of its own needs during these periods.
- When cells photosynthesise, availability of O_2 not a problem in these cells since O_2 is released within cells

This is also facilitated by — Loose packing of parenchyma cells in → roots, → stems, → leaves (which provide interconnected network of air spaces)

- Complete combustion of glucose yeilds energy which is given out as heat.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

Key is to oxidise glucose in several steps enabling some steps to be just large enough such that energy released can be coupled to ATP synthesis. & not all liberated energy goes out as heat.

GLYCOLYSIS

originated from → GREEK WORDS → Glycos means → sugar
Lysis means → splitting

EMP pathway — because its scheme was given by → Gustav Embden, Otto Meyerhof, J. Parnas

* The only process in respiration in anaerobic organisms
* occurs in → cytoplasm
* present in all living organisms
* Glucose undergoes → partial oxidation → to form → 2 mol. of pyruvic acid

* In Plants → Glucose is derived from Sucrose → from → end product of photosynthesis; from → storage carbohydrates
* Sucrose —invertase enzyme→ (Glucose + Fructose) → readily enter into Glycolytic pathway
* Glycolysis is → chain of ten reactions → under control of different enzymes
* Glucose & Fructose —phosphorylated to give (Hexokinase)→ Glucose-6-phosphate —isomerases to→ Fructose-6-phosphate → Subsequent steps are same in glucose & fructose.
* Pyruvic acid is → Key product of Glycolysis
  - its → metabolic fate → depends on → Cellular need.
  - Its fate depends on → O_2 availability; organisms

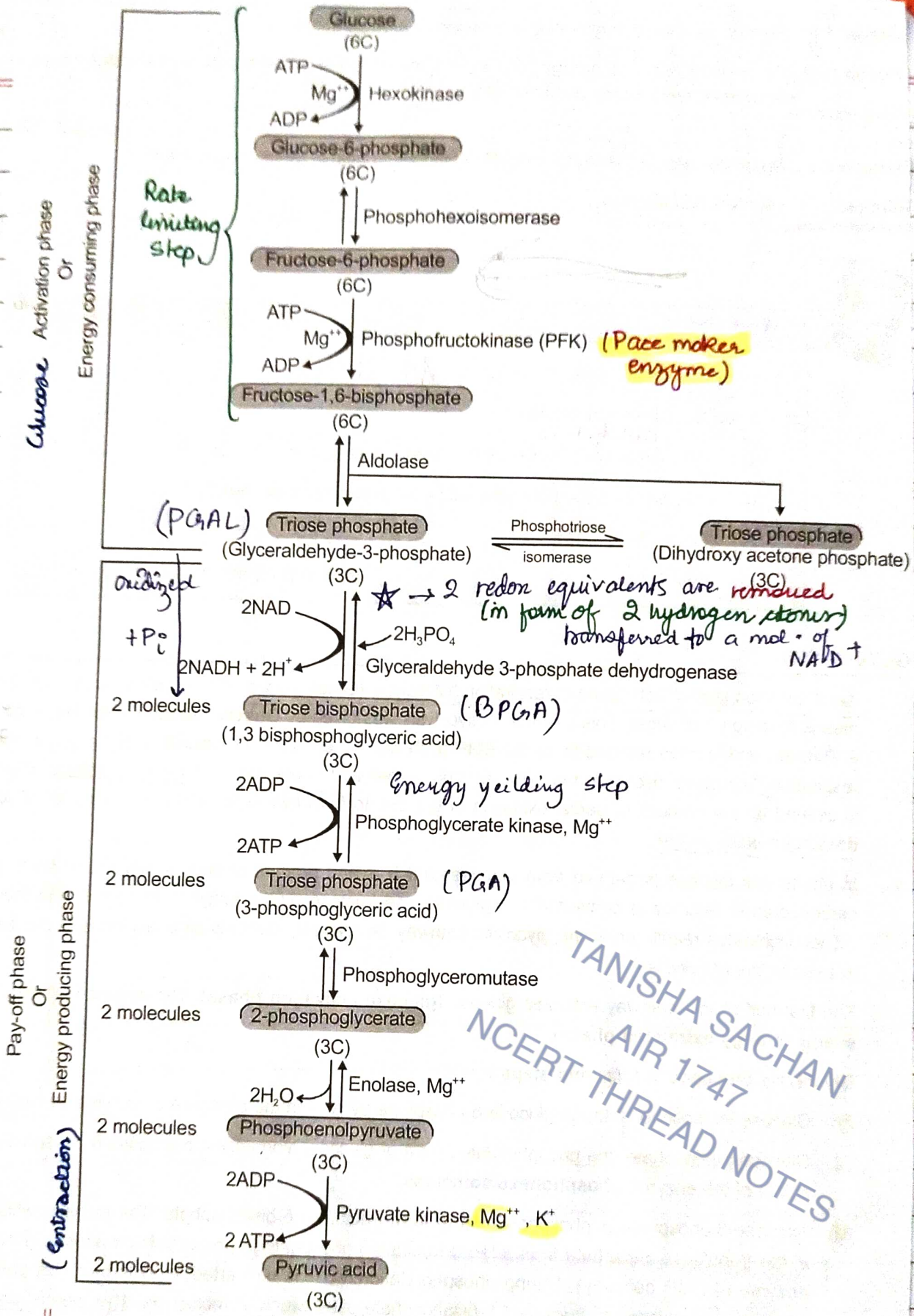
3 major phase in which different cells handle Pyruvic acid

- LACTIC ACID FERMENTATION
- ALCOHOLIC FERMENTATION
- AEROBIC RESPIRATION

* Fermentation takes place under → anaerobic conditions → in → many prokaryotes; unicellular Eukaryotes

Major pathways of Anaerobic Respiration

Glucose
↓
Glyceraldehyde-3-phosphate
↓ NAD+ → NADH + H+
3 phosphoglycoric acid
↓
Phosphoenol pyruvic acid
↓
Pyruvic acid
- → Lactic acid (NAD+ → NADH + H+)
- → Ethanol + CO_2 (NADH + H+ → NAD+)



Fermentation takes place in → prokaryotes
→ unicellular eukaryotes
→ Germinating seeds

FERMENTATION → by yeast

→ incomplete oxidation of glucose → under → anaerobic condition

* Enzymes that catalyze these rxns → by sets of rxn where → pyruvic acid → converted into → Ethanol + CO_2

PYRUVIC ACID DECARBOXYLASE

ALCOHOL DEHYDROGENASE

Some Bacteria → produce → Lactic Acid from pyruvic acid

* In ANIMAL CELLS (Ex- Muscles) → during excercise → when O_2 is inadequate for → cellular respiration → Pyruvic acid

In both → LACTIC ACID FERMENTATION, ALCOHOL FERMENTATION → < 7% energy in glucose is released.

Lactic acid → ① reduced by ② lactate dehydrogenase ③ Reducing agent → NADH + H^+

NAD+ ← regenerated to (in both process)

HAZARDOUS PROCESSES as → acid / alcohol → is produced

→ not all of it is trapped as → High energy bonds of ATP

YEAST — poison themselves to death → when → concentration of alcohol reaches 13%

AEROBIC RESPIRATION

most common in HIGHER ORGANISM

→ In eukaryotes takes place in → Mitochondria

→ Requires → O_2

Leads to → Complete oxidation of organic subs (in presence of O_2) & releases

① H_2O ② CO_2 ③ Large amt of energy

* Final product of glucose : Pyruvic acid → transported to → Mitochondria

CRUCIAL EVENTS

→ matrix of mitochondria → Complete oxidation of pyruvate by → Step-wise removal of all H-atoms leaving → 3 CO_2

→ Passing on of the e^- removed as part of Hydrogen to → molecular O_2

→ inner membrane of mitochondria → Simultaneous synthesis of ATP with

Pyruvate → formed by → Glycolytic catabolism of → carbohydrate in → Cytosol.

after it enters → Mitochondrial matrix → it undergoes → oxidative decarboxylation by → complete set of reaction

① Coenzyme A ② NAD+ ③ several coenzymes & Pyruvic dehydrogenase catalysed by

* Pyruvic acid + CoA + NAD^+ $\xrightarrow[\text{Pyruvate dehydrogenase}]{Mg^{2+}}$ Acetyl CoA + CO_2 + NADH + H^+

* During this process — 2 (NADH + H^+) produced from 2 pyruvate (by 1 glucose)

⊙ Acetyl CoA → enters → cyclic Pathway → Tricarboxylic Acid Cycle (Krebs Cycle)

elucidated it ← who first ← Hans Krebs ← named after

TRICARBOXYLIC ACID CYCLE

⊙ Starts with — Condensation of acetyl group + OAA & water (to yeild) Citric acid

Rxn is catalysed by Citrate Synthase & a mol. of CoA

⊙ Citrate —(then isomerised to)→ Isocitrate —(1 cycle of decarboxylation)→ α-Ketoglutaric acid —(1 cycle of decarboxylation)→ Sucanyl CoA —(oxidised to)→ OAA —(allows cycle to continue)→ OAA

⊙ Succinyle CoA —(1 GTP)→ Succinic Acid [Substrate level phosphorylation]

* GTP is converted to GDP with simultaneous synthesis of ATP (from ADP)
* 3 points in cycle — NAD^+ reduced to $NADH + H^+$
* 1 point in cycle — FAD^+ reduced to $FADH_2$
* OAA → Ist member of the cycle
  → Its continuous replenishment req. for continued oxidation of acetyle CoA in TCA.
* Also req → regeneration of NAD^+ & FAD^+ from NADH & $FADH_2$.
* Till now released → 8 mol $NADH + H^+$, 2 mol $FADH_2$, 2 mol ATP → by 1 glucose

Summary Eqn.

$$\text{Pyruvic acid} + 4NAD^+ + FAD^+ + 2H_2O + ADP + P_i$$

(mitochondrial matrix)

$$\rightarrow 3CO_2 + 4NADH + 4H^+ + FADH_2 + ATP$$

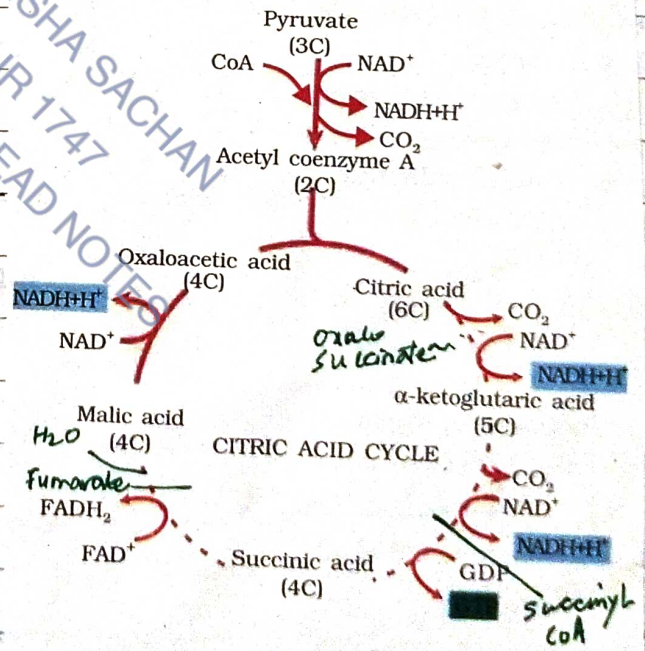


Figure 14.3 The Citric acid cycle

Electron Transport System (ETS) & Oxidative phosphorylation

→ To release & utilize the energy stored in NADH + H⁺ & FADH₂

This is accomplished by → these are oxidized through → ETS → e⁻ are passed on to → O_2 resulting in formation of → H_2O

(* Metabolic pathway through which e⁻ passes from one carrier to other)

ETS (e⁻ transport system) present in → Inner mitochondrial membrane.

NADH gives → e⁻ oxidized by → NADH Dehydrogenase (complex 1) → e⁻ then transferred to → Ubiquinone (Located within the inner membrane)

NADH produced in → Mitochondrial matrix during → CAC

Ubiquinone → reduced to → Ubiquinol → loses e⁻ via → Cytochrome bc_1 complex (complex -III)

Ubiquinone → reducing equivalents → $FADH_2$ (complex -II)

Cytochrome bc_1 complex → to → Cytochrome C

- Small protein
- attached to outer surface of inner membrane.
- Acts as - mobile carrier for transfer of e⁻ b/w complex III & IV

Cytochrome C → Cytochrome-c-oxidase (complex -IV)

- Contains → Cytochrome a, a_3
- 2 copper centres

When e⁻ pass via complexes I → IV → from one carrier to other in ET chain → they are coupled to → ATP synthase (complex V) → for production of → ATP (from ADP & $P_{inorganic}$)

* No. of ATP synthesized → depends on → Nature of e⁻ donor.

1 mol. NADH gives → 3 ATP

1 mol. $FADH_2$ gives → 2 ATP

* Although aerobic process of respiration → takes place → only in presence of oxygen. → Role of O_2 is limited to terminal stage of process.

Yet O_2 presence is vital since it drives whole process → by removing hydrogen from the system → Oxygen acts as Final acceptor of H_2.

Also, O_2 is Ultimate acceptor of e⁻ → O_2 gets reduced to H_2O.

In photophosphorylation — light energy → is utilised for phosphorylation → prod. of proton gradient ← req. for

In respiration — Energy of Oxid.-Reduction is utilised for phosphorylation

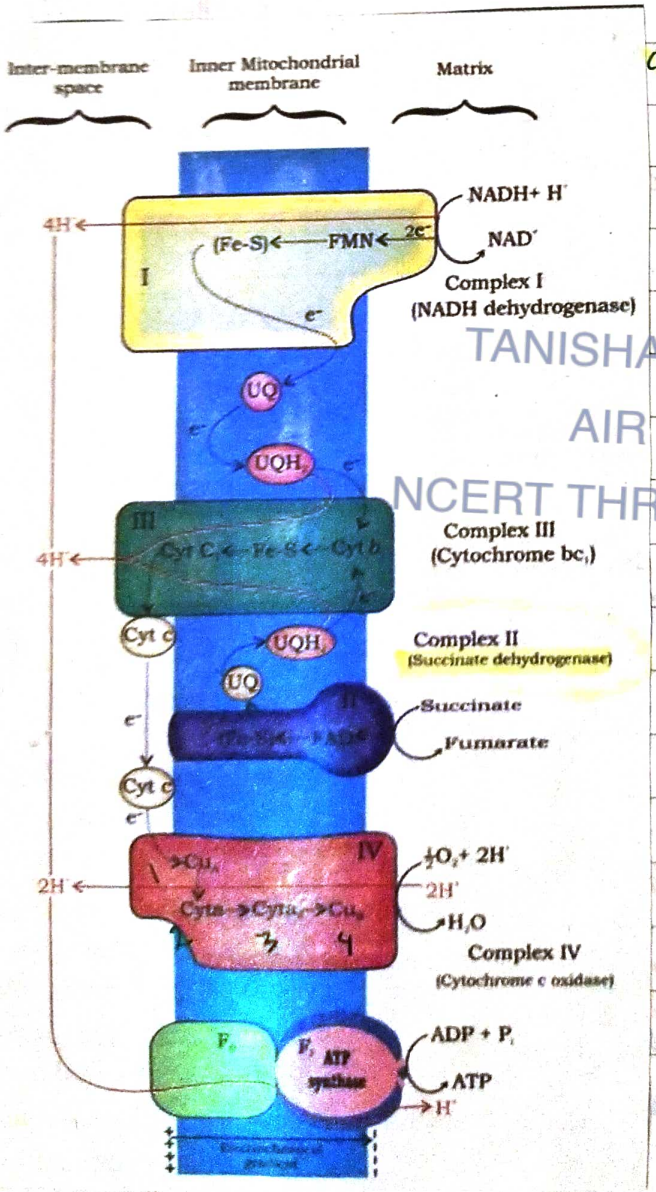
↳ Hence called — **OXIDATIVE PHOSPHORYLATION**

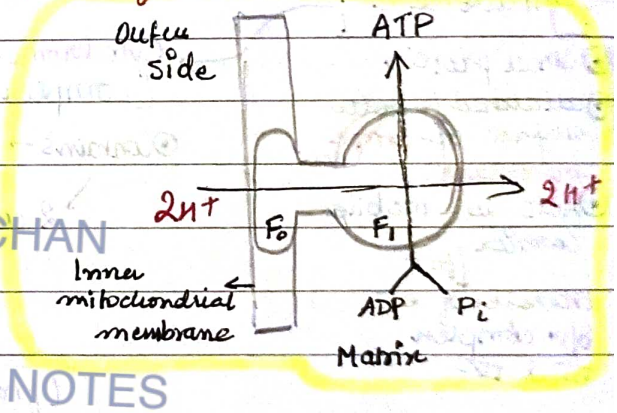
Complex V → ATP Synthetase consists of 2 major components → F_1, F_o

F_1 headpiece	F_o
⊙ Peripheral membrane protein complex	⊙ Integral membrane protein complex
⊙ Contains – site for synthesis of ATP from ADP & Pinorg.	⊙ Forms a channel through which protons cross the inner membrane

* Passage of protons through channel → coupled to → Catalytic site of F_1 component → for the production of → ATP.

* For each ATP produced ⟶ $2H^+$ passes through F_o from mitochondrial matrix to the intermembrane space (down the electrochemical proton gradient)





(complex I → FMN → Fe-S → UQ) — complex III (UQ → Cyt c_1 ← Fes ← Cyt b ← UQ) — Comp II — Cyt c → (Cu$_A$ → Cyt a → Cyt a_3 → Cu$_B$) — comp. IV

RESPIRATORY BALANCE SHEET

Theortical excercise

Certain assumptions

Sequential Orderly pathway functioning with one substrate forming the other
Glycolysis → TCA → ETS

NADH synthesised in Glycolysis → transfered to Mitochondria → undergo → oxidative phosphorylation

None of intermediate utilised to synthesise any other comp.

Only glucose being respired
(No other alternative substrate are entering pathway at any of intermediatary stages)

This kind of assumptions → not valid → in a living system
All pathways → work → simultaneously
ATP → utilised as when needed
Sysbstrate → withdrawn as when necessary
Enzymatic rates controlled by multiple means

Net gain - 38 ATP
(during aerobic resp of 1 mol. glucose)

Fermentation

Partial breakdown of glucose.
Net gain = 2 ATP (degraded to Pyruvic acid)
(NADH → oxidized → NAD^+) slowly

Aerobic Respiration

Completed degradation of glucose into CO_2 & H_2O
Net gain = more
Vigorous here

AMPHIBOLIC PATHWAY

Glucose → favoured substrate for respiration

All carbohydrates → are usually first converted into Glucose → then used for respiration

Other substrate respired → do not enter pathway at 1st step

Fats → Fatty acids → degraded into → Acetyl Co-A → enter pathway
Fats → Glycerol → converted to PGAL → enter pathway

Proteins → degraded by Proteases → individual AA (after deamination) depending on their structure → would enter Krebs cycle as → pyruvate or acetyl co-A

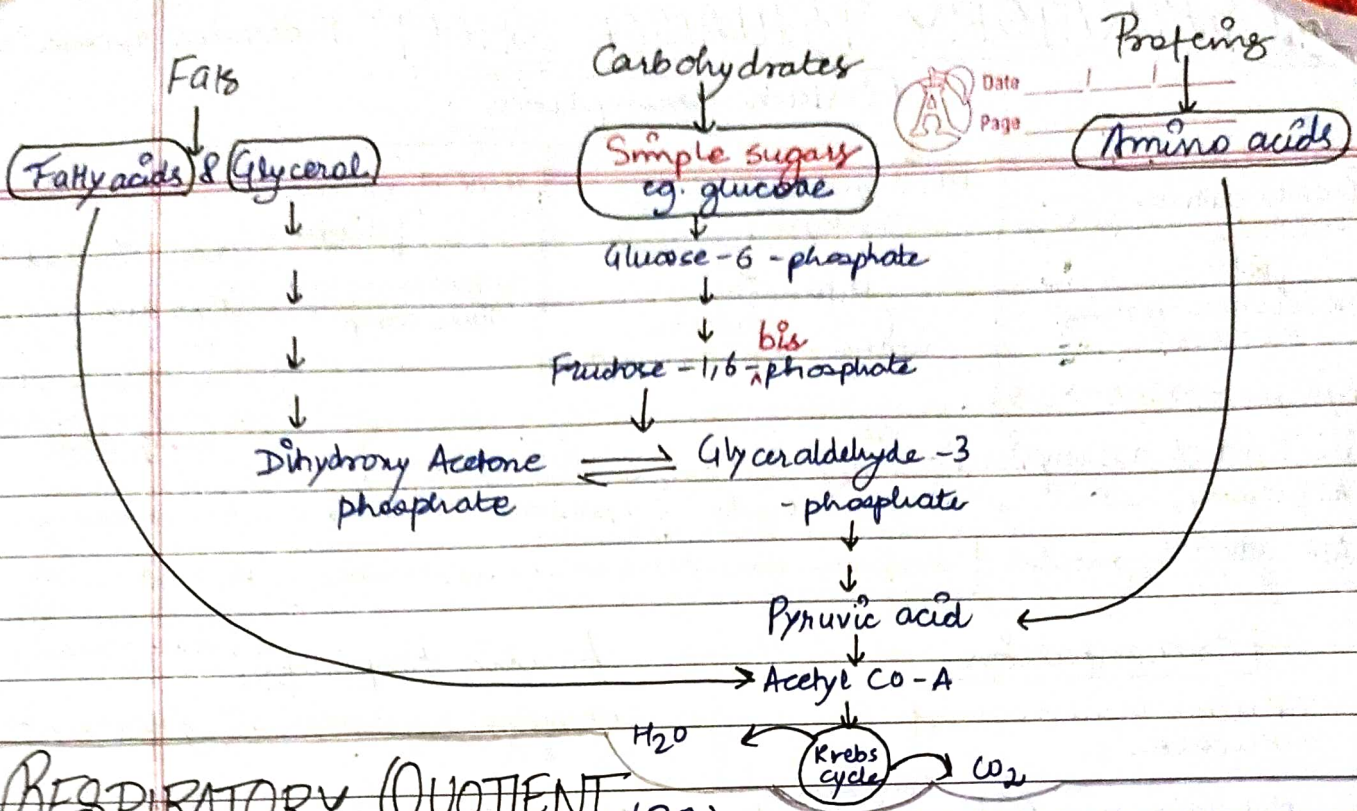
Very comp. are within own respiratory pathway. for the synthesis of said substrates.

Fatty acids → broken to → Acetyl co-A → before entering respiratory pathway
but other → Organism need to synthesise fatty acids
Respiratory pathway → would be withdrawn from → Acetyl Co-A

Similarly, during breakdown / synthesis of protein → respiratory intermediates form the link

Breakdown of substrate - catabolism
Synthesis - anabolism

Respiratory pathway → involved in both → anabolism + catabolism → hence it's → Amphibolic pathway



RESPIRATORY QUOTIENT (RQ)

$$RQ = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ consumed}}$$

RQ depends on → type of respiratory substrate

Carbohydrates

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

$$RQ = \frac{6CO_2}{6O_2} = 1.0$$

Fatty acids

RQ < 1 ≈ 0.7

Example, Tripalmitin

$$2(C_{51}H_{98}O_6) + 145O_2 \longrightarrow 102CO_2 + 98H_2O + \text{Energy}$$

$$RQ = \frac{102CO_2}{145O_2} = 0.7$$

Proteins

RQ < 1 ≈ 0.9

Imp. Note ⇒ In Living Organisms → Respiratory substrates often more than one (1)

but

[Pure proteins] [Pure fats] → never used as respiratory substrate

ATP ACCOUNT / Balance Sheet (At a glance)

ATP account	Direct synthesis	In ETS		ATP consumed	Net gain
		From $[NADH + H^+]^*$	From $FADH_2$ **		
From glycolysis	**4**	**6** From $2 \times [NADH + H^+]$	Nil	**2**	**8**
From acetylation of pyruvic acid	Nil	**6** (From 2 pyruvic acid)	Nil	Nil	**6**
From Krebs' cycle (from 2 cycles)	**2**	**18** From $6 \times [NADH + H^+]$ (3 in each cycle)	**4** From $2 \times [FADH_2]$	Nil	**24**
Total gain	**6**	**30**	**4**	**-2**	**38**

* One $[NADH + H^+]$ can give 3 ATPs (when enters the ETS)

** One $FNDH_2$ can give only 2 ATP (when enters the ETS)

In this calculation, two turns of Krebs' cycle have been considered. This is because, one glucose produces two pyruvic acid and two acetyl CoA. Hence two cycles occur for each glucose molecule.

Mitochondria which are produced outside of mitochondria (i.e., in cytoplasm) can give only 2 ATPs under physiological conditions. So, final net gain per glucose is only **36 ATPs.**